

# Globalization of Innovation and Dynamics of a Regional Innovation Network: The Case of the Canadian Fuel Cell Cluster

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**Abstract**— The Canadian Fuel Cell Cluster began its integration in the eighties in response to military intelligence policy recommendations, but its particular configuration and dynamics have been changing over time. This paper presents a longitudinal analysis of its development. Fieldwork was done through interviews conducted in 2005 and 2007-8. Results show some ways in which the role of the main actors, linkages and processes responsible for the cluster formation and evolution change over time. We provide a brief history of the fuel cell cluster and a description of its current characteristics and dynamics. We make particular reference to factors that they respond to, such as policies, market expectations, industry structure, and government economic support, for example, in order to explain the current cluster configuration as an open international innovation network, rather than as a local or regional one, a fact that challenges previous knowledge in this field.

**Index Terms**—Innovation cluster; fuel cell; cluster dynamics.

## I. INTRODUCTION

EVEN as many successful innovation clusters have been documented in the literature [47], [38], [31], [50], [5], [19], [6], [14], [28], [12], in most cases their analysis and description has been made *ex post facto* considering only successful cases [20]. Many questions remain about how regional innovation systems develop and about those processes and stages they must overcome in order to achieve significant innovation capabilities that enable them to compete successfully with other regions.

Indeed, since many of the essential characteristics of successful innovation networks are emergent properties of complex systems [22], [17], most studies have implicitly assumed that the occurrence of significant innovation clusters

is an unpredictable outcome of processes that are difficult to ascertain. Many local, regional and national governments, however, look closely at studies in this field, in an effort to identify policy implications that may enable the development of new and dynamic innovation clusters.

The specialized literature has identified and documented the actors that participate in those innovation networks and the roles they play. Garnsey [22], for example, has discussed the fact that successful innovation networks typically include components such as a leading scientific university or big firms with significant R&D capabilities, science and technology parks, a desirable social environment, provision of venture capital, a highly-skilled labour pool, and public support for innovative technology. All of these factors are present in Vancouver: research universities are present, Ballard has developed a technological leadership throughout several decades, technology parks and industrial infrastructure are present and a highly-skilled labour force has also developed along the years. Vancouver's natural and social environment are highly regarded in the country and abroad, venture capital is quite active in the province and the success of other innovation networks (such as the biotechnology and the multimedia clusters, for example, is proof to the strength of its social capital [2]).

But a successful and dynamic innovation network is more than an aggregate of firms and R&D activity, even in the presence of other facilitating factors. In some cases, interaction among actors in the system need to give rise to emergent properties: i.e. properties that arise as activities of individual but interdependent actors attain a coherence and synergy that is absent in many other social and economic contexts. To the extent that that interaction begins to give rise to a collective identity and collective learning processes [34], [10], [39], [37], shared knowledge begins to facilitate interaction among members of the network, and knowledge flows increase the efficiency of innovative activities. It is not only the presence of these factors and resources, but the ability of different regions to turn them into specific and competitive competencies for innovation [44].

A key dimension in the emergence of innovation clusters, and one which has been widely discussed [45], [30], [21], [24], [46], [16], [1], [20], [11], [3], is also that of geographical proximity, as many of the processes that build up innovation capabilities essentially depend on it [43], [4]. These processes include the sharing of tacit knowledge [34], [10], [38] the

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agglomeration of human capital, R&D capabilities and investment, venture capital, the development of favourable institutional contexts [40], [35], [36], [13], etc.

A competing idea is that knowledge flows and availability, R&D outsourcing and collaboration linkages with players from outside the regional domain make it difficult for a regional innovation system to be self-contained, so that external linkages are essential to their development [48], [25], [6], [11]. Some authors have reported this as a growing tendency in innovation networks in specific industries, such as biotechnology [27], [15], as firms increasingly seek to obtain the complementary assets needed to exploit and commercialize their technologies in a global environment and to compensate for size-inherent disadvantages [7]. Under certain conditions, these processes may generate competing forces that pull away from the regional concentration of innovative capabilities.

There still are, however, important questions about how different environmental factors influence the collective behaviour of individual actors in the system as government policies, technological hurdles and economic uncertainties alter their patterns of interaction and entrepreneurial decisions [8], [23]. Indeed, government policies and governance structures may alter the ways in which firms seek and establish alliances for research and development, as well as the knowledge that flows through those alliances [49]. As patterns in these decisions emerge, they may significantly alter the development path for the innovation network and its eventual success as a regional innovation system. As well, even as many of those conditions and components which are present in successful innovation networks (such as social capital and collective learning processes, for example) may be present in promising contexts, different factors may affect the outcome.

What are the key emergent processes in the development of a regional innovation system? How do systemic processes arise from individual action, particularly in the context of small firms' strategic decisions and alliances? How do these decisions give rise to regional capabilities that enable a regional network to successfully compete with other regions? Where do those forces that pull away from regional agglomeration effects create an equilibrium, or even override those forces that pull in those factors that enhance innovation capabilities? Could a threshold effect be present? And if so, how could it be characterised?

The Innovation Systems Research Network in Canada has conducted a parallel longitudinal study of several innovation networks as they developed in the first years of this century. Their achievements are well documented<sup>1</sup>. In what follows, we present evidence on key processes that shape the development and outcomes of the fuel cell innovation cluster in Vancouver, Canada. We attempt to provide a longitudinal analysis of its development, tracking the effect of environmental, technological and market factors in decisions

made by entrepreneurs and other actors in the cluster.

Fieldwork was done through interviews conducted in 2005 and 2007-8. Interviews were conducted with firm founders and CEO's, with higher management in non-governmental organizations, trade associations and public research organizations, as well as university research labs. Some of the interviews in 2007-8 were conducted as part of the ISRN City/Region Initiative [32]. Interviews were semi-structured and some of the questions directly addressed the research questions that this paper is concerned with.

Interviews from the different periods were transcribed and coded with the aid of content analysis software (NVivo-NUD\*IST) in order to identify strategic decisions dealing with the issues this research aimed to explore. Decisional categories, for example, were defined in terms of theoretically-based concepts while some others were inductively derived from the review of the interview material itself. Interview fragments were sorted into those categories and further coded, as either forces that pulled towards the integration of the regional innovation system or forces that pulled away from it. Node structures were built in order to group coded fragments and to identify emerging patterns at an aggregate level. Interview fragments included here are regarded as most illustrative of the processes and categories identified.

## II. BRIEF HISTORY OF THE FUEL CELL INNOVATION CLUSTER

Ballard Power Systems was founded in 1979 under the name Ballard Research Inc. in Vancouver, British Columbia, to conduct research and development in high-energy lithium batteries. In response to a call for proposals from the Canadian Government, in 1983 it began to develop fuel cells as a renewable power source. This federal government's initiative can be tracked to a military intelligence unit singling out this technology for its potential for significant civil and military applications. In close relationship with the University of Victoria [29], Ballard began to develop the fuel cell technology, with the principal aim of developing automotive applications.

By 1994, the company had developed proof-of-concept fuel cells and by 1994 it had full-scale prototype systems to demonstrate the technology. Widely recognized as the technological leader in the world during the 1990's and early 2000's, Ballard began attracting other players into the innovation network. New companies were founded to develop and to exploit different technologies related to PEM (proton exchange membrane) fuel cells.

In the late nineties and in the beginning of this century the fuel cells cluster in Vancouver began to give rise to many important components and conditions that have been found to be associated with successful innovation networks in other contexts. Among those components and conditions a significant pool of highly-skilled labour force, as well as new firms that were spun-off from Ballard and from other public and private organizations could be found. Even though they were latecomers to this collective innovation effort,

<sup>1</sup> A comprehensive bibliography may be found in: <http://www.utoronto.ca/isrn/publications/index.html>.

universities began to develop stronger research efforts in the field, and a network of firm alliances associated with different aspects of technology development and exploitation began to arise.

The National Research Council of Canada began to support the development of the British Columbia fuel cell cluster in 1998, assigning to the Institute for Fuel Cell Innovation the mandate of working in partnership with universities, government agencies and companies on projects focused on the research, development, demonstration and testing of hydrogen and fuel cell systems, in an attempt to become the hub of fuel cell innovation in the province of British Columbia and in the country. Headquartered in Vancouver, Hydrogen & Fuel Cells Canada was created in 2000 as 'Fuel Cells Canada', but the association later changed its name in 2006 to Hydrogen & Fuel Cells Canada, in order to reflect the broader interests of its growing membership. Thus, industrial partners, universities, public R&D institutions, trade associations and non-governmental organizations collectively deployed an effort to develop a successful innovation network. Canada's Fuel Cell Research Initiative was launched in 1999 and it mobilizes resources from across the country in order to strengthen R&D efforts in this field.

Thus, by the end of last century, the Vancouver fuel cells innovation network seemed to be poised for a very strong and dynamic leadership in automotive applications. It displayed the right set of conditions and factors for growing into a full-fledged cluster [29]. Indeed, a sizable highly-skilled workforce had been developed and their experience in the field was significant:

“And there's a good labour force here, that we can tap into. I'd say that that is the main benefit (of being located in Vancouver).”

“Well, we do hire from the talent pool locally. Because we have good talent pool here (...) we are close to the US, it's the farthest we've brought anybody from. We haven't actually brought anybody from overseas yet. We have quite an international company, but they all found their way here first. Except for a couple who we got outside of Canada, looking, as we couldn't find anybody locally who had the necessary skills (...) It's gotten a lot easier in the last two years, because some of the other fuel cell companies have started to have some troubles. So, as they slowed down, and shrunk a little bit, their labour force has opened up. The first two or three years it was very difficult to find labour, extremely difficult to find labour. It's gotten a lot easier.”

However, centrifugal forces have also arisen, that have prevented these components from maturing into a full-fledged innovation system. Among these centrifugal forces we find the technological and economic uncertainties that prevented the full-scale commercialization of the technology, as well as the fact that the provincial and the federal governments would not keep public investment in the technology at the level deemed

by private firms to be necessary.

For a long time, Ballard was regarded as the engine of innovation in the fuel cell network in Vancouver, and the international leader in this respect. However, it recently sold its automotive fuel cell effort to a transnational company. Many start up companies have migrated into other markets, and the Canadian effort in this domain seems to be losing ground against foreign competitors. The story of the fuel cell innovation network seems thus to follow a different path from those other innovation networks that have appeared and developed in the region, such as the biotechnology and the multimedia innovation networks.

Given that so many factors were present for the development of the fuel cell innovation cluster, it remains a question whether it will become a successful innovation cluster, particularly as it competes with other regions in the world for the central role in the development of the technology. In spite of those many positive factors, some centrifugal forces have shaped the cluster's trajectory in a manner that doubts remain about its ability to maintain its international leadership. We discuss some of these centrifugal forces in the following section.

### III. CENTRIFUGAL FORCES

One of the strongest external influences comes from the economics field, and it is the “goods complementarity” problem and its network effects [41], [33]. Fuel cells applications in the automotive industry depend on the availability of fuelling infrastructure, markets for this technology have been slow to arise. These systems have little or no value in isolation from each other, but investment in each one of them is of a magnitude that is beyond individual actors in the system to tackle. Therefore, it is a matter of public investment being sustained to a level where private firms are able and willing to invest and run the corresponding risks. In the view of many actors in the system, government investments in these efforts have been insufficient, in the context of very strong international competition:

“(...) in recent years there's been a lot of concern that the amount of money that (the country is) spending in alternative energy technologies, and particularly in fuel cells is just peanuts compared to what's going on in the United States. You know, we have about 20 million in a fuel cell innovation centre, compared to 2 billion promised throughout the US. It's just a different order of magnitude. (...) There's concern in the Vancouver cluster that different companies in the States will be unsurpassable...”

“Personally, I don't think that the national government is doing enough (...) A good effort, that I believe was supported by the national government and by the Fuel Cell Innovation Centre was the Fuel Cell Commercialization Roadmap (...) that was a good effort, it was largely industry-led, which is the way it should be (...) but I haven't seen evidence of any of

those recommendations being put together, yet (...) they talk about having the federal government subsidize different sectors of the economy, different industries, vertical, that would then use fuel cell products, so that it would stimulate growth, much as it is done in Japan, and I just haven't seen any of that as of yet."

"If we are going to take advantage of the current scientific leadership, and market leadership that Ballard has, you know, it is a critical few years..."

"... there are companies in Canada that have leadership positions, but international competitors are catching up. We have had a leadership position in Canada in certain fields, such as components and materials, (but) other areas are becoming more active, spending more dollars, becoming more competitive, which is certainly eroding some of the Canadian leadership, but I believe that Canada still has a fundamental lead in certain areas, and one of the key areas is certainly the fuel cell stacks."

But also, fuel cell technology is only a part of drive train and ancillary component technologies which are needed for automotive applications to become economically viable. Power trains include many components, such as stacks, electric drives, ancillary control systems, hydrogen sources, etc. Besides that, their automotive applications require hydrogen containers and safety devices, among many others. The complexity of these power trains has given rise to opportunities for start up companies that exploit different niches and markets.

This shortage of public funds has led firms and research institutions to look elsewhere for the expertise and investment in order to maintain the leadership that the principal actors in the system have enjoyed. They seek knowledge, expertise and economic resources that are essential for the maturing and delivery to market of this technology. Fierce competition leads firms to seek allies abroad, and not only within the regional context:

"Yes, (our firm) partners with other R&D firms. We leverage the expertise of other institutions and universities, but (the firm) does not limit that to local companies. Because we are an international business, we need to find the best, so we have some partnerships with US universities, we have some partnerships with German universities, we have some partnerships with institutions in Asia. Quite frankly, we will find the best to take care of our technology and business."

"We think globally. Ours is a global business. We think it's a very big business. We're not interested in a small company. We're interested in a global player. And, to the extent that we can keep as much as that as possible happening in this area, we would like that to happen. But, very honestly, if the conditions were such that we had to relocate to Taiwan or Northern Ireland, or

wherever, we would. This is not to say there wouldn't be a long conversation, but I know what we would do."

"... we work with universities all over Canada (...) local players haven't been, particularly important to us in the start up phase. They can't move fast enough to be of help. They're too slow."

But the private sector has also been waiting for demand and commercialization to arrive. Technological and economic hurdles have been difficult to overcome, and delivery of the technology to market has taken much longer than anyone had foreseen. As a result of these delays, start up firms have been forced to turn away from automotive applications and look into different business propositions and markets, drifting away from the initial interaction with other players in the system:

"The company was founded and initially funded on the basis of the applications of its technology with fuel cells, and specifically for uses in automotive fuel cells. So the company raised a fair bit of money, initially from venture capitalists, and then from Ballard, and then from institutional investors, to pursue the application of its technology to on-board fuel cells, such as cars, and we worked for several years very closely with..., initially with General Motors, and then with Ballard and Daimler-Chrysler, on the development of the technology that would go into large-scale deployment of fuel cell cars, that was supposed to happen in 2006, 2007. Of course, the fuel cells technology for automobiles is taking a lot longer to get to commercialization than what people had hoped. And so, there was a lot of money that was spent in a lot of technology development that was done early in the decade, that never got to the commercial market, because the commercial market never developed..., has not yet developed. I mean, I think most of us are of the view that at some point it will be a commercial technology, but it is not commercial now. So the company got to a point where it doubled our technology development and spent a lot of money on that technology development. And we looked forward, and we saw that it was still going to be several years before there was really a market from which we could generate any revenue. And so we sat down as a group, and had a discussion about what could the company do, because it couldn't continue to raise money for a market that was always going to be, you know, seven to ten years away. And so we looked at how could the technology be applied in existing markets, you know, that could generate revenue and cash flow today, so that you could build a business and continue to have exposure to the hydrogen economy, for the time when it actually became a commercial market, so we made a pretty fundamental change in our strategy in 2003, to focus much more so on existing industrial markets."

When stakes in the development of a new technology are high, such as in the fuel cell industry, external players tend to

seek participation in it, but in those cases the intellectual property regime may substantially hinder collaboration among the local network. The basic tenet of “untraded interdependencies” may be overcome by the need for the establishment of substantial intellectual property rights:

“We seek non-disclosure agreements, and agreements on intellectual property, and all you can do is trust that your (international) partners will abide by those agreements, but if they don’t, there’s legal action we can take.”

“We have between 80 and a hundred assets that are in process of being patented. It is hard to know if those patents mean a competitive advantage, until afterwards. One thing I know is that I don’t want to regret that we didn’t patent something... ‘I wish I had patented that’. We are fortunate with our capital resources and with our investors, that they appreciate the possible importance of the patents. So, I really don’t know how important patents are, and I don’t think we can tell you, until the company is in the Fortune 100, you know, that patents were important or not, but at this early stage it seems to us that all we have is the knowledge. All we have. We don’t have manufacturing, we don’t have channels to market, we don’t have relationships. All we have is what we know. So, the way to communicate that value to investors and others is with the patent portfolio that formalizes that knowledge into discreet assets. So that’s why we take it so seriously.”

“So, when we started the company we’ve taken patents very seriously from the beginning, and we’ve always had an awareness of the intellectual property portfolio of the perceived leaders in the field, and we do an IP watch constantly. So we are always on the lookout of what’s going on around us.”

“Yes, we have an IP portfolio where a number of patents are in pursuit and more that will certainly be at it. We have licensed some technologies, patented technology; and we are also working with our suppliers on their own intellectual property as well; so we are working within a pretty strong intellectual property or intellectual capital environment here.”

“We are very aggressive in patenting. That is one of the things: we patent both for the sake of potentially cross licensing and collaborating with others on intellectual property, but also from a defensive point of view, so that anything we actually conceive we are not prevented from using because of someone else’s patents. I would say that is probably the key to, or the philosophical basis of, our intellectual property, but we also don’t see intellectual property as being the only way to advance the company. I mean, ultimately we have to sell product and gain revenue and that comes from including our intellectual property in our products, rather than, we are not strictly setting ourselves to license what we develop.”

“Our patents are all generated in-house. Our patents are few, and very specific, because they are expensive to

maintain. One of our electro chemists in our research team writes patents. (...) We found out that patents are expensive to maintain. We try to restrict ourselves to essentially very, very specific patents. Our patents are few, and very specific. (...) You need them to raise money, especially when people invest.”

But all of this activity of protecting technologies in development slows down progress and makes start up firm shy away from immediate local collaboration. The network becomes more a global network than a local one. As the technology matures and start up companies feel the need to deliver products to market, they will seek partners with the ability to provide them with a platform from which to advance in this process:

“We are working with our collaborative partner in California on a number of projects that are in the US market. One of them is a military project; others are in the domestic auto manufacture. We are putting at least as much emphasis on opportunities that we see developing in other parts of the world, notably in China, because we see the automotive industry in China developing very rapidly needing this kind of technology, as everyone else does, and also becoming a major force in the world, actually in automotive supply, partly because of cost, but also because they can afford to develop their capability just on their own domestic market as well...”

“Everybody is..., every customer is really looking for product from a development and preproduction point of view, so we are in the prototype development with a number of the OEM’s...”

Together, all of these processes represent centrifugal forces that move individual firms away from partnerships with local players and to seek partners in industries other than the one where their initial technological capabilities were developed. It turns out then that, what used to be thought of as a fuel cell cluster, has become two or more different clusters [29].

#### IV. DISCUSSION AND CONCLUSIONS

We provide a brief history of the fuel cell cluster and a description of its current characteristics and dynamics. Throughout the process, however, we find that the Vancouver fuel cell is gravitating towards a type of innovation network that is different from those regional innovation clusters documented in the literature. In sharp contrast with other innovation networks in the same locality, we find rather a case of what some authors [31] see as a trend towards global, rather than local innovation networks.

Possibly because of the size of the investments involved (both public and private), and maybe also because of the high stakes that this technology involves, individual decisions shift away from a network business culture based on strong local

ties [10], [37], [9] towards one based in the selection of the best global players in the relevant fields. According to our findings, local actors seem to relinquish the value of proximity and face-to-face interaction, in favour of previously existing talent in other regions. Our case study shows those processes by which globalization reduces the significance of the local context as the primary source of innovation [26], and the motivations of different actors as they make the relevant decisions with regards to their search for relevant knowledge and expertise.

Evidence from our fieldwork shows some ways in which the role of the main actors, linkages and processes responsible for the cluster formation and evolution not only change over time, but that they do not necessarily gravitate towards local collaboration and alliances. As has frequently been documented in the literature, usually regional innovation systems must also establish links with external sources of knowledge and other inputs. Es explained above, these external linkages are usually associated in the literature with knowledge, human capital and financial capital flows and considered to help the regional innovation system to strengthen its capabilities. However, as we have shown, as firms try to leverage their assets by establishing alliances with firms or research institutions outside the local context, they also acquire commitments that pull their interests and resources away from the regional network. As start up firms face the challenge of a protracted commercialization process, and the difficulty of achieving economic and technological milestones, they resort to external alliances and they enter emerging international intellectual property markets that further hinder their reliance on local networks and resources. As industrial markets fail to materialize in the expected time periods, start up firms are also forced to look into existing markets away from those they initially aimed for. This process eventually leads to specialization and diversification of talent and expertise in domains different from the initial ones.

In the Vancouver fuel cell cluster many external forces increasingly drive the action of different players toward strengthening contractual obligations and property rights and toward international, rather than towards local collaborations (untraded interdependencies). Pressure from international competition drives local firms and organizations to establish external links when seeking to partner with the best sources of expertise around the world, but these partnerships come at a price: capital flows and intellectual property obligations weaken local ties, while strengthening commitment to non-local interests. As firms seek new sources of capital, they naturally look at their most important assets as leverage to attract it. In the process, however, they become pawns in multinational corporations' strategies, to the detriment of their local relationships with other regional actors. The development of an international market for intellectual property is a recent phenomenon [42] but, as interviewees' statements reproduced here show, firms in the Vancouver cluster are actively entering it.

Even though it may still be early in the process, evidence presented here points to the possibility that these centrifugal

forces may actually hamper the integration of a regional innovation system, eventually leading to its fragmentation or disintegration, in spite of the presence of many factors usually associated with successful development of a local innovation system.

Indeed, it will not necessarily be the case that the Vancouver fuel cell cluster becomes a hub for international R&D in automotive fuel cell power trains, even if it aspires, in the words of some interviewees, to specialize in the R&D or knowledge-generating aspect of the industry. In one scenario, the huge stakes that international players have in the development of this technology, and the size of other international investments, will end up constraining R&D efforts to be deployed within specific multinational firms or consortia. In terms one of the questions posed above, it could very well be the case that the Vancouver fuel cell cluster did not achieve the threshold level that would be necessary to withstand the effect of the centrifugal forces identified. The phenomenon may also be described under the framework used by Rodríguez-Pose and Crescenzi [45]: the Vancouver cluster would lose the battle against the 'tectonic forces' that shape mountains in an otherwise flat world, forces that may eventually overcome its ability to become a mountain.

On the other hand, as managers and technical personnel, the entrepreneurial talent and the high-calibre workforce tend to stay in the area, they are beginning to find opportunities in clean energy, in the hydrogen economy and in related fields. It would then mean that indeed a local innovation network will develop, although in a much wider sense in terms of the technological specialties and the specific industries served. If this happens, it will be a challenge to the traditional definitions of regional innovation networks, as innovation capabilities are currently spreading out to wider and wider industrial domains

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